SECTION 7: IMPACT OF WEIGHT CHANGES ON AIRCRAFT FUEL CONSUMPTION[1]

[Note: This section was added to the internet version in February 1999. It will be incorporated in subsequent revisions of the printed version.]

7.1 INTRODUCTION

This section considers the impact of aircraft weight changes on their fuel consumption. It presents estimates of incremental aircraft fuel consumption caused by small increases in aircraft weight. These estimates can be used to determine the fuel consumption impacts associated with operational or regulatory changes that affect the operating weight of aircraft.

The incremental fuel burn data are presented for three different classifications:

- by the Federal Aviation Regulation (FAR) governing certification (FAR's 23, 25, 27, and 29),
- by economic values class (as described in Section 3), and
- by user profile (scheduled commercial service: air carrier without commuters and commuter only; non-scheduled commercial service or air taxi; and general aviation).

The relationship of these categories to each other as well as the specific aircraft used to represent each are indicated in Table 7-1. The fuel consumption impacts reported are based on industry accepted fuel burn models and manufacturer's specifications. Because existing fuel burn data and models are aircraft specific, utilizing this information required identifying specific aircraft to represent the various classification categories. Sub-section 7-2 addresses the identification of corresponding representative aircraft. Details of the fuel burn models, how they were employed to generate the required estimates, and the incremental fuel consumption estimates are presented in sub-section 7-3.

[1] The information presented in this section is drawn from "Impact of Weight Changes on Aircraft Fuel Consumption—Final Report," Federal Aviation Administration, October 19, 1998. This report is itself an update of "Impact of Weight Changes on Aircraft Fuel Consumption," Federal Aviation Administration, March 17, 1994.

Table 7-1
Aircraft Classification Categories and Representative Aircraft

FAR Category	Economic Values Class	Representative Aircraft by User Profile			
		Scheduled Commercial Service	Air Carrier w/o Commuters	Commuters	Air Taxi and General Aviation
FAR 25: Transport	Jet: 4 engine wide body	B-747-400	B-747-400		
	Jet: 4 engine narrow body	DC8-62	DC8-62		
	Jet: 3 engine wide body	DC10-30	DC10-30		
	Jet: 3 engine narrow body	B727-200	B727-200		
	Jet: 2 engine wide body	B767-332ER	B767-332ER		
	Jet: 2 engine narrow body	B737-300	B737-300		
	Jet: Regional under 40 seats	LR35-35		LR35-35	
	Jet: Regional 40-59 seats	CL600-2B19		CL600-2B19	
	Jet: Regional over 59 seats	F100-100		F100-100	
	Jet: Corporate				LR35-35
	Turbo Prop: 20+ seats	Saab 340		Saab 340	Saab 340
FAR 23: Commuter	Turbo Prop: under 20 seats	Metro III		Metro III	Metro III
Normal, Utility, & Aerobatics	Piston: Multi-Engine	Beech-B55		Beech-B55	Beech-B55
	Piston: Single Engine	Cessna-172		Cessna-172	Cessna-172
FAR 27: Normal	Turbine Rotorcraft: <6000 lbs.				B212
FAR 29: Transport	Turbine Rotorcraft: >6000 lbs.				MBB 125

7.2 SELECTING REPRESENTATIVE AIRCRAFT

The aircraft fleet tends to change over time. Key determinants of fleet composition change are technological advancements including noise reduction technology. This update of weight penalty estimates captures these changes through the selection of aircraft representative of those that can be expected to be operated in the foreseeable future. The determination of the representative aircraft in each category was based on the following criteria:

- Ability to Meet Stage 3 Standards,
- Frequency of Use,
- Average Takeoff Weight, and
- Fuel Consumption

Aviation noise has become an important issue for the Federal government. Much emphasis has been on large jet airplanes (over 75,000 pounds). This emphasis began in the early 1960's with the rapid expansion of turbojet aircraft into the civil aviation market. It led to the first noise certification standards in 1969, establishing Stage 2 standards for new airplane types. This was followed successively by setting Stage 3 standards in 1977 and the phase-out of Stage 1 airplanes in 1985. Recognizing that the Airport Noise and Capacity Act of 1990 (ANCA) will require that all civil subsonic turbojet airplanes over 75,000 pounds operating to or from airports in the contiguous United States be Stage 3 compliant by December 31, 1999, representative aircraft selected for this effort are limited to those capable of meeting Stage 3 requirements.

The other criteria were used to ensure that selected aircraft be representative of the overall fleet. Potential representative aircraft, indicated for each group in Tables 7-2 through 7-15, were those that exhibited a relatively high frequency of use. These aircraft were then compared on the basis of average takeoff weight and fuel consumption. The aircraft ultimately selected are highlighted in the tables. Incremental fuel burn estimates for these aircraft are reported Table 7-16.

7.2.1 FAR 25 Aircraft

FAR 25 regulations relate to transport category airplanes. Tables 7-2 through 7-11 display aircraft categories, categorized by the number of engines (2, 3, or 4), the type of body (wide or narrow), the type of engine (jet or turboprop), the number of seats for regional jets, and common use (private or commercial) that were considered. The tables list the aircraft type, average takeoff weight, and fuel burn in gallons per hour. The representative aircraft in all categories exhibit high frequency of use, typical fuel burn performance and characteristic takeoff weight.

Table 7-2
Characteristics of 4 Engine Wide Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds[2]	Total Fuel Burn in Gallons per Hour[3]
BOEING 747-100	750,005	3,638
BOEING 747-200/300	786,000	3,663
BOEING 747-400	870,000	4,018

Table 7-3
Characteristics of 4 Engine Narrow Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
BAE-146-2	90,375	817
BAE-146-3	97,250	642
DC-8-62	348,000	2,489
DC-8-63	350,300	2,283

Table 7-4
Characteristics of 3 Engine Wide Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
DC-10-1	438,500	2,287
DC-10-3	572,000	3,130
LOCKHEED -1011	430,000	2,428
LOCKHEED -1011-5	501,500	3,829
MD-11	612,714	2,462

[2] Data obtained from the Aircraft Noise Data listed on the FAA web page: (http://www.aee.faa.gov/aee-100/)
[3] Fuel Burn data from Aircraft Operating Statistics 1997 published by the Air Transport Association (http://www.air-transport.org/data/ff97/acrftst.htm) and NavTech Systems Support of Waterloo Canada.

Table 7-5
Characteristics of 3 Engine Narrow Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
BOEING 727-200	209,500	1,844

Table 7-6
Characteristics of 2 Engine Wide Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
AIRBUS -300-600	355,000	1,678
BOEING -767-2/ER	360,500	1,409
BOEING -767-3/ER	412,000	2,001
BOEING -777	548,000	2,117

Table 7-7
Characteristics of 2 Engine Narrow Body Jets Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
AIRBUS 320-1/2	156,000	820
BOEING 737-1/2	124,500	824
BOEING 737-3	125,500	851
BOEING 737-4	142,500	792
BOEING 737-5	132,800	747
BOEING 757	235,000	1,050
DC-9-10	90,700	743
DC-9-30	107,000	810
DC-9-50	118,000	915
MD-80	149,500	933

Table 7-8
Characteristics of Regional Jet under 40 Seats Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
LEAR-24	13,500	209
LEAR-25	15,000	209
LEAR-35	18,000	197

Table 7-9
Characteristics of Regional Jet with 40-59 Seats Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
CANADAIR CL600	51,000	382
CANADAIR CL601	43,100	348

Table 7-10
Characteristics of Regional Jet with 40-59 Seats Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
FOKKER -100	98,000	726

Table 7-11
Characteristics of Turbo Props 20 or more Seats Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
SHORT-360	25,750	165
SAAB-340	28,000	129
DASH-8	33,000	167
EMBRAER -120	25,353	160

7.2.2 FAR 23 Aircraft

FAR 23 regulations relate to commuter, normal, utility and acrobatic airplanes. Tables 7-12 through 7-14 present the aircraft, categorized by the type of engine (piston or turboprop) and the number of engines (single or multiple), that were considered. The tables list for each aircraft type, the average takeoff weight and total fuel burn. The representative aircraft exhibit high frequency of use, typical fuel burn performance, and characteristic takeoff weight.

Table 7-12
Characteristics of Turbo Props under 20 Seats Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
BEECH 100	11,800	59
DASH 6	11,000	55
KING AIR B200	12,500	48
METRO-III	14,500	72

Table 7-13
Characteristics of Multi Engine Pistons Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
BEECH 55	5,200	25
PIPER 31	6,000	21
CESSNA 310	5,000	27

Table 7-14
Characteristics of Single Engine Pistons Considered

Aircraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons per Hour
CESSNA 172	1,700	12
CESSNA 182R	2,850	11
PIPER 32	3,600	13

7.2.3 FAR 27 and FAR 29 ROTORCRAFT

While there are a large number of rotorcraft types that fall into the two categories defined by FAR parts 27 and 29, the representative aircraft were selected based in part on those for which reasonable fuel burn information was available. Research was conducted with the assistance of aircraft experts from Navtech Systems in Canada to select two rotorcraft within the regulatory categories.

The selection of these aircraft considered availability of fuel burn data, as well as the criteria listed earlier in this section (i.e., airborne hours and speed, average takeoff weight, frequency of use and fuel consumption). The following two aircraft were selected based on this criteria.

Table 7-15
Characteristics of FAR 27 and FAR 29 Rotorcraft Considered

Rotorcraft Type	Average Takeoff Weight in Pounds	Total Fuel Burn in Gallons Per Hour
FAR 27: MBB[4] 125	3500	25
FAR 29: Bell 212	7500	45

7.3 FUEL CONSUMPTION ESTIMATES

This sub-section presents the estimates of incremental fuel consumption for each of the 15 aircraft categories. Data sources, estimation techniques, and assumptions used in developing these estimates are also described.

7.3.1 Estimation Procedure

Incremental fuel consumption for FAR 25 and FAR 23 turbo-prop aircraft was estimated using an industry accepted fuel burn model.[5] The fuel burn model calculates en route fuel burn assuming International Standard Atmospheric (ISA) conditions using a formula specific to aircraft type, series and engine combinations, and flight path. The model uses climb, cruise, descent, and holding performance data obtained from operator flight manuals or from manufacturers' data. Reported estimates are derived by fitting regressions to the results obtained by processing several hundred flight plans.

The fuel burn model could not be used to develop estimates of incremental fuel consumption for multi-engine and single-engine piston aircraft in the FAR 23 category and

[4] Messerschmitt-Bulkow-Blohm Gmbh predecessor of Daimler-Benz Aerospace company.
[5] The fuel burn model was developed by Navtech Systems Support Inc. of Waterloo Canada.

rotorcraft in the FAR 27 and 29 categories because of data limitations. For these aircraft, fuel consumption was calculated manually using methodology identical to the fuel burn computer model.

For each particular aircraft type, the base fuel burn was calculated for a user-specified takeoff weight and en route time. The fuel consumption based on a specified increase in takeoff weight was then calculated. The difference in the two calculations is the incremental consumption resulting from the additional weight. For each aircraft two input values were required: takeoff weight and average flight time in minutes. For takeoff weight, the analysis used the aircraft's maximum gross takeoff weight (MTOW) with three exceptions: the DC10, B737, and CL600 (RJ). This is because one of these aircraft departing at MTOW and flying for the specified time would not have burned sufficient fuel to be below its maximum structural landing weight. For these three aircraft, the analysis used a baseline takeoff weight that would result in the aircraft arriving at destination at the maximum landing weight.

In the case of rotorcraft (FAR 27 and 29), further assumptions were required in order to determine the incremental fuel consumption. Fuel burn analysis for these categories is complicated by the fact that flight plans are rarely consistent for rotorcraft in terms of flight times, altitudes, and maximum speed. The fuel burn analysis assumes cruising altitudes of 6000 feet for the B212 rotorcraft and 4000 feet for the MBB 125 rotorcraft and corresponding maximum speeds. These are representative cruising altitudes for rotorcraft in a commercial environment. En route time for both rotorcraft is assumed to be one hour.

7.3.2 Incremental Fuel Consumption Estimate

Incremental fuel consumption estimates, expressed in gallons per airborne hour per pound increase, are presented in Table 7-16. Because typical weight penalties for FAR 25 aircraft may range from under 50 pounds up to 500 pounds, the table provides fuel consumption estimates for various weight increments within this range. Inspection of the estimates indicates that the relationship between the weight increment and additional fuel consumed is close to being linear (i.e., the fuel penalty per pound weight increase does not vary significantly with the increment of weight).

Typical weight penalties for FAR 23, 27 and 29 aircraft range up to 100 pounds. Because of the smaller range and expected linear relationship between weight increases and additional fuel consumed, the table reports an estimate for only one weight increment—0 to 100 pounds.

Table 7-16
Estimates of Incremental Fuel Consumption by Aircraft Classifications

See Table of Contents for Table 7-16

Table 7-17 explains how to use the estimates reported in Table 7-16 to calculate specific weight penalties. For any particular aircraft, it is necessary only to multiply the gallons per hour per pound from Table 7-16 by the incremental weight. The result is additional fuel that can be expected to be burned per hour because of the increase in weight.

Table 7-17
Example of Weight Penalty Calculation

FAR 25 Category: Jet: 3 Engine narrow **Representative Aircraft:** B727-200			
Weight Increment	**Incremental Gallons per hour per pound (Table 7-16)**	**Calculation**	**Fuel Burn Estimate (Gallons per airborne hour)**
Weight Increment 1: 30 Pounds	0.010103	0.010103 * 30	0.30307
Weight Increment 2: 62 Pounds	0.010104	0.010104 * 62	0.626448
Weight Increment 3: 250 Pounds	0.010108	0.010108* 250	2.52700

7.4 SUMMARY ESTIMATES PER CATEGORY

Table 7-18 presents a summary of incremental fuel burn, assumed en route times, and gallons per hour. The summary values are derived by taking a weighted average across the economic value classes operated by each user group or certified under each respective FAR. Each economic value class is represented by its representative aircraft as shown in Table 7-16. For the user class summary, the weights are the airborne hours flown by each respective user class in all aircraft belonging to each economic value class. For the FAR summary, the weights are the airborne hours flown by all aircraft in each economic values class certified under each particular FAR.

Table 7-18
Summary Table for Fuel Consumption Estimation by User and FAR Categorie

See Table of Contents for Table 7-18